



Multistage Fusion Reaction Rates in an Adiabatically Compressed Plasma

David W. Kraft
School of Arts & Sciences
University of Bridgeport, Bridgeport, CT

and
Robert G. Butler
Department of Natural Sciences
Baruch College, New York, NY

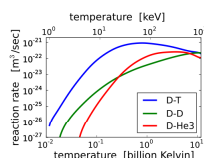
What is Nuclear Fusion?

Energy is released when light nuclei fuse to form heavier nuclei. This is the energy which powers stars such as the Sun. The amount of energy released is related to the difference in the masses of the initial and final nuclei according to $E = mc^2$.

Nuclear forces are of short range. Hence reactions occur only when nuclei are in close proximity and to achieve this they must have energy sufficient to overcome their repulsive electrostatic forces. This requires such high temperatures as 15,000,000 K as in the Sun.

Challenges and objectives

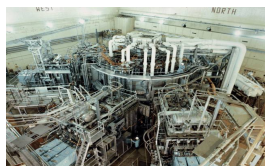
- Achieve temperatures such as that in the Sun's interior;
- Confine reacting species long enough for fusion reactions to occur;
- Achieve energy break-even: output energy compensates input energy.



Two Major Approaches to Fusion

Magnetic confinement. A low density plasma of H^+ ions is confined by magnetic fields.

Inertial confinement. A pellet of solid H is bombarded by high-intensity lasers.



Primary reactions:

$D + D \rightarrow T + p + 4.03 \text{ MeV}$; $D + D \rightarrow {}^3\text{He} + n + 3.27 \text{ MeV}$
 $\langle \sigma v \rangle \approx 10^{-14} T^{-2/3} \exp(-19T^{-1/3}) \text{ cm}^3/\text{s}$ for $T < 50 \text{ keV}$

Secondary reactions

$D + T \rightarrow \alpha + n + 17.6 \text{ MeV}$; $D + {}^3\text{He} \rightarrow \alpha + p + 18.3 \text{ MeV}$

Fusion reaction rates proportional to n^2 .

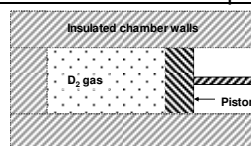
n = particle density.

Magnetic confinement methods: $\approx 10^{15} \text{ cm}^3 \Rightarrow$ requires $T \approx 10^8 \text{ K}$

Proposed Method

Exploit n^2 factor under reduced degrees of freedom
 Perform under adiabatic conditions
 \Rightarrow appreciable fusion rates at lower T

Mechanical adiabatic compression



Dense gas of D_2 undergoes adiabatic compression
 Rapid process - explosively driven
 Well-insulated chamber - retain energy internally

Starting conditions.

One mole D_2 at atmospheric pressure and room temperature.

Apply compression. Compression factor $\beta = V_0/V$. T increases.
 D_2 molecules $\rightarrow D_2$ atoms $\rightarrow D_2$ atoms ionize
 \rightarrow deuteron-electron plasma \rightarrow Fusion of deuterons.

Assumptions:

Reversible adiabatic compression
 Apply equilibrium thermodynamics
 Treat as *van der Waals* (vdW) gas: $(P + aN^2/V^2)(V - Nb) = RT$

Degrees of freedom

γ = specific heat ratio

Related to number of degrees of freedom f of the gas: $\gamma = (f + 2) / f$

For monoatomic gas: $f = 3$

Deprive particles of freedom of motion \Rightarrow larger T increase for given energy input. Accomplish with

- (1) External magnetic field(s)
 - (2) Electric discharge in direction of piston motion.
- Also \Rightarrow Pinch Effect.

Adiabatic compression of a vdW gas

$$T = T_0 \left(\frac{V_0 - Nb}{V - Nb} \right)^{\gamma-1} = T_0 \left(\frac{\beta(V_0 - Nb)}{V - \beta Nb} \right)^{2/f}$$

Work to compress a van der Waals gas

$$W = - \int_{V_0}^V P dV = \frac{NRT_0 f}{2} \left[\left(\frac{\beta(V_0 - Nb)}{V_0 - \beta Nb} \right)^{2/f} - \beta^{-2/f} \right] - \frac{aN^2}{V_0} (\beta - 1).$$

Energy release

Reaction rate: $r = \frac{1}{2} n^2 \langle \sigma v \rangle$

σ = reaction cross section; v = relative velocity of interacting nuclei

Energy release in time Δt : $\Delta E = r Q V \Delta t$. V = final volume

Q = avg energy release/reaction. Previously considered fusion to occur only at end of compression. Present work computes T and ΔE at various stages of the compression.

$f = 1, \beta = 150$

Multistage data for vdW gas

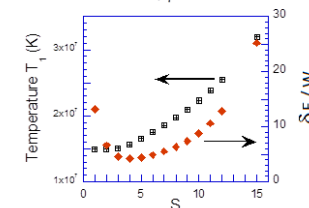
Consider only D+D: Avg $Q = 3.65 \text{ MeV}$

Calculate final T and $\Delta E / W$ as

function of total no. of stages S .

Total $\Delta t = 0.001 \text{ sec}$.

T and $\Delta E / W$ vary directly with S .



Applications

Single shot: Neutron source to initiate fission.

Multiple compressions in dual chambers.

Dual pistons with coil to extract work



Summary and conclusions

Exploited n^2 factor and reduced degrees of freedom.

Adiabatic conditions \Rightarrow energy retained internally.

Found some favorable cases.

To be more realistic:

Not all input energy serves to compress gas.

Consider particle losses via leakage.

Compensated by ignoring:

D-T reactions; Pinch Effect.

Enhancements: Deuterated walls; Screening effects of electrons.